THE IMPACT OF SOIL AND VEGETATION MANAGEMENT ON ECOSYSTEM SERVICES IN EUROPEAN ALMOND ORCHARDS

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Abstract

This study examines the use of green manure, no-tillage and compost to improve nutrient cycling and plant species richness. Therefore we conducted a full factorial design with four treatments in five almond plantations. The treatments include the business as usual management, conventional tillage (CT) and no-tillage (NT), compost (CM) and green manure (GM). Soil enzymatic activity was used as a proxy for nutrient cycling and plant richness and cover for habitat provisioning. Phosphatase activity increased with 50% in the alternative treatments, and the activity of glucosidase was twice as high in CM compared to CT. Plant species richness was highest in NT, but the vegetation cover was found to be equal in GM and NT. To conclude, implementing green manure, no-tillage and compost application on a monoculture almond farm appear to be effective strategies to improve ecosystem services provided on the farm, such as nutrient cycling and plant species conservation.

Keywords: ecosystem services; agroecology; conservation agriculture; tree-crop; nutrient cycling; habitat provisioning

Introduction

Over 30% of Mediterranean Europe is experiencing degradation of biophysical processes on land (Zdruli 2014). Within Europe, Spain has the largest issues related to land degradation as an estimated 12.5 % of the total territory is degraded (Bai et al. 2008), moreover other authors are even estimating that the extent of the problem is reaching 28 – 54 % of the territory (Dregne 2002). Tree-crop systems play an important role in the reduction of ecosystem services due to the widespread conventional management. In this conventional management, clean sweeping is a common practice whereby soils are frequently tilled to assure that understory vegetation is permanently removed (Meerkerk et al. 2008). This management results in a loss of soil of 5.70-10.5 Mg ha-1 yr-1 and runoff of 10.9-58.1 mm ha^{-1} (Durán Zuazo and Rodríguez Pleguezuelo 2008). Additionally, the removal of understory vegetation in almond orchards is estimated to reduce the abundance of pollinators by 64.3-86.8 % (Norfolk et al. 2016; Saunders et al. 2013). Moreover, the frequent tillage practices are driving the breakage of soil aggregates and the loss of 20 – 30 % soil organic carbon pool (West and Post 2002). This physical degradation of the soil negatively affects the abundance and activity of soil biota that play a crucial role in belowground ecosystem processes (Barrios 2007). Nonetheless, recent evidence is mounting to show that alternative land management practices, such as cover crops or natural vegetation covers, reduced or no-tillage and organic soil amendments, can contribute to the rehabilitation of biophysical and ecological processes in almond orchards (Ramos et al. 2010; Almagro et al. 2013; Saunders et al. 2013; Ramos et al. 2011; Duran Zuazo et al. 2008; Martínez Raya et al. 2006; Macci et al. 2010). However, all these studies have been conducted on just a single, or in some cases two experimental sites making it difficult to draw conclusions related to best management practices. Therefore, this study experimentally tested the use of green manure, no-tillage and compost applications in five farms, to assess their impact on nutrient cycling and on habitat provisioning for plant species.

Enzymatic activity was assessed as a proxy for nutrient cycling service in the soil. Soil enzymatic activities have been proven to be a powerful tool to assess soil quality as they respond rapidly to changes in soil management (Burns et al. 2002). For this study, the enzymes β-Glucosidase, Phosphatase, Urease and Dehydrogenase were chosen because they catalyse the hydrolysis of organic compounds. They give an indication for the decomposition processes in the soil, as they are indicators for the breakdown of cellulose (β-Glucosidase) and the P-cycle (Phosphatase), N-cycle (Urease) and C-cycle (Dehydrogenase) (Das and Varma 2011).

Materials and methods

The research was conducted in the high planes of the provinces Granada and Almeria in the East of Andalusia, SE Spain.

Experimental design

We conducted a full factorial design with four treatments in five existing almond plantations. On each farm a homogeneous site was chosen where the four treatments were randomly implemented, a treatment within a farm is hereafter referred to as a ‘plot’. Each plot corresponded to a rectangular area of at least four by eight trees, but only the inner two rows with almond trees were included in the research, to optimize the effect of the treatment and exclude the influence of adjacent management. The dimensions of the research plots were then 14 m x 56 m = 784 m^2 (7m average distance between trees), and included a minimum of 15 trees (Figure 1).

In each farm, the four plots were implemented as follows:

CT – Conventional tillage: the plot is tilled 2-3 times a year to remove the understorey vegetation using a cultivator.

NT – No-tillage: the plot is not tilled and has spontaneous understory vegetation.

GM –Green Manure: Common vetch (*Vicia sativa*; 50 kg ha^{-1}), Bitter vetch (*Vicia ervilia*; 50 kg ha^{-1}) and Barley (*Hordeum vulgare*; 20 kg ha^{-1}) were sown in the plots. Seeds were mixed in a ratio of 5:5:2 and were sown by hand in December 2016 in a quantity of 120 kg ha^{-1}. After sowing, a cultivator passed to incorporate the seeds into the soil. In addition, after the ground cover sampling, between the end of May and the beginning of June, the ground cover was plowed into the soil with a cultivator.

CMP – Compost, type Bokashi: the plot is fertilized with compost, which was purchased from a local vendor (Moreno Basura - Maria, Alméria). The compost was applied in December with a quantity of approximately 6 m^3 ha^{-1} and incorporated in the soil with a cultivator. During the rest of the year, the plot was tilled 1-2 times to remove weeds.

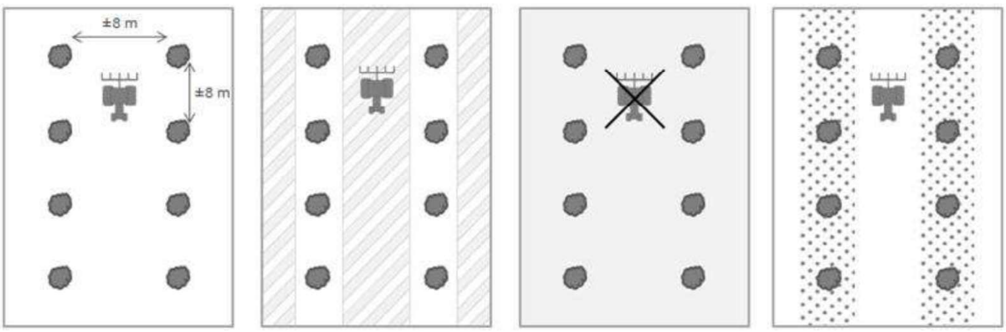

Figure 1: Schematic overview of the four treatment plots. a) tillage (CT), b) green manure (RTGM), c) no-tillage (NT), d) compost (CM). White soil color indicates bare soil, grey indicates permanent vegetation, white/grey stripes indicate inpermanent vegetation (green manure seed mixture), dots indicate that compost is applied.

Soil sampling

In each plot three soil samples of 1-2 kg were taken in April 2017, each consisted of ten sub-samples that were randomly taken from the 0-20 cm soil layer from the plot. Soil samples were sieved at field moisture through a 2 mm sieve. The samples were stored at 4°C until lab analyses.

Enzymatic activity

Dehydrogenase activity was measured according to the methodology described by García et al. (1997). To assess the Phosphatase activity and β-glucosidase we used the methodology of Ramos et al. (2011). Urease activity was determined according to Nannipieri et al. (1982).

Vegetation sampling

The ground cover vegetation composition was assessed in May 2017 using the point-intercept method, modified as proposed by Ruiz-Mirazo and Belén (2012). In each treatment plot, six 10 m long transects were randomly laid out, and each consisted of one hundred points measured at a distance of 10 cm. At each point of the transect, a needle of 30 cm was put in the ground and all plants that touched the needle were identified to the species level. When there was no plant touching the needle, we recorded bare soil. From these data, we calculated vegetation cover (%) and plant species richness (number of species per unit area).

Statistical analysis

Data was analysed with a generalized linear mixed model to test the effect of the treatments on enzymatic activity, vegetation cover and plant species richness by using the lme4 package in R. In this analysis the treatments were taken as a fixed factor and the farms were taken as a random factor.

Results

We found a significant effect of treatment on soil enzymatic activities (Table 1), especially for the enzyme phosphatase, where CT (conventional tillage) was related to a lower enzymatic activity than the three other treatments, NT (no tillage), GM (green manure) and CM (compost). We found that urease in NT was twice as high than CT, however this was not significant, also the activity of this enzyme in CM and GM was higher than CT. Glucosidase enzymatic activity was higher in CM than CT, however, GM and NT did not statistically differ from the other treatments, but had on average higher activity than CT. Dehydrogenase activity was not influenced by the treatments.

Both vegetation parameters turned out to be significantly affected by the implemented management regimes (Table 1). The plant species richness was significantly higher for NT treatment, followed by GM treatment. CM and CT had on average lower plant species richness. Vegetation cover was significantly lower in CT than in all other treatments, except for CM. This was mainly due to the large variation in cover in the compost treatment.

Table 1: Mean values ± standard error of the activity of dehydrogenase (mgr INTF h^{-1}), glucosidase (mgr PNP h^{-1}), phosphatase (mgr PHO h^{-1}), Urease (mgr NH4 h^{-1}), and vegetation cover (%) and plant species richness (# species $transect^{-1}$), for the treatments conventional tillage (CT), no-tillage (NT), green manure (GM) and compost (CM).

ES indicator	p-value	CT		NT		GM		CM	
Nutrient cycling									
Dehydrogenase	0.7	2.1 ± 1.4		2.7 ± 1.9		2.5 ± 1.9		2.7 ± 1.5	
Glucosidase	0.01	140 ± 78	b	365 ± 215	ab	270 ± 97	ab	330 ± 140	a
Phosphatase	0.001	102 ± 72	b	157 ± 59	a	150 ± 59	a	159 ± 67	a
Urease	0.6	33 ± 32		65 ± 50		51 ± 30		55 ± 35	
Habitat provisioning									
Vegetation cover	1E-07	25 ± 25	b	72 ± 27	a	72 ± 18	a	34 ± 43	b
Plant species richness	1E-07	6.3 ± 5.1	b	11.2 ± 2.9	a	7.4 ± 3.0	ab	5.3 ± 4.6	b

Discussion

In this study we found that improved management practices, such as green manure, no-tillage and compost application, played a significant role in the rehabilitation of soil services provisioning and plant species conservation. The enhancement of phosphatase activity in all treatments compared to conventional tillage shows that the capacity to release organically-bound phosphorus may be increased with improved management practices leading to a boost in the P-cycle for the benefit of all plants present including the almond trees. Additionally, we found that dehydrogenase, an enzyme that plays a role in the decomposition process within the C-cycle, is not sensitive to changes in these soil and vegetation management practices. The other enzymatic activities, that play roles in the N-cycle and P-cycle and in the breakdown of cellulose, have shown to be enhanced after implementation of these management practices. To improve plant species richness, no-tillage management is most effective. However, for increasing vegetation green manure is just as effective.

To conclude, implementing green manure, no-tillage and compost application on a monoculture almond farm appear to be effective strategies to improve and rehabilitate ecosystem services provided on the farm, such as nutrient cycling and plant species conservation.

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